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PAPER

Children's coding of human action: cognitive factors influencing imitation in 3-year-olds

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Abstract

We used imitation as a tool for investigating how young children code action. The study was designed to examine the errors children make in re-enacting manual gestures they see. Thirty-two 3-year-old children served as subjects. Each child was shown 24 gestures, generated by systematically crossing four factors: visual monitoring, spatial endpoint, movement path, and number of hands. The results showed no difference as a function of whether the children could visually monitor their own responses. Interestingly, children made significantly more errors when the adult's action terminated on a body part than they did when the same movement terminated near *the body part. There were also significantly more errors when the demonstrated act involved crossing midline than when it did not, and more errors when it involved one hand rather than two hands. Our hypothesis is that human acts are coded in terms of goals. The goals are hierarchically organized, and because young children have difficulty simultaneously integrating multiple goals into one act they often re-enact the goals that are ranked higher, which leads to the errors observed. We argue that imitation is an active reconstruction of perceived events and taps cognitive processing. We suggest that the goal-based imitation in 3-year-olds is a natural developmental outgrowth of the perceptual–motor mapping and goal-directed coding of human acts found in infancy.*

Imitation depends on the perception and coding of actions. In this paper we use imitation as a tool to investigate how young children code the actions they see others perform. We are as interested in the errors children make in attempting to re-enact actions as we are in their correct copying. Our starting assumption is that imitation is an active reconstruction of an observed event. We sought to uncover factors that facilitate and dampen imitative accuracy with an eye towards specifying the perceptual–motor and cognitive factors involved in imitation.

Early work on the brain and cognitive mechanisms in imitation was conducted by Head (1920, 1926). He used adult patients with brain lesions (caused by gunshot wounds) and tested their ability to duplicate simple gestures such as touching the ear with the hand on the same side as or the opposite side of the body to the ear (ipsilateral and contralateral movements). The main finding was that the adult patients performed much more poorly on the contralateral gestures than the ipsilateral ones, although normal adults did not have such problems. According to Head, 'none of the normal men I have examined failed to recognize that when the left hand was in contact with the right ear it had crossed the face; and yet this want of appreciation of crossed movement was one of the commonest pathological mistakes' (Head, 1926, Vol. I, pp. 157–158).

This effect was replicated in normally developing children from 3.17 to 18 years and was dubbed the contralateral inhibition effect (e.g. Gordon, 1923; Swanson & Benton, 1955; Wapner & Cirillo, 1968; Schofield, 1976). Kephart (1971) speculated that this effect reflects neurophysiological immaturity that prevents children from producing cross-midline gestures.

Recently Bekkering, Wohlschlaeger and Gattis (2000) tested children ranging between 3.8 and 6.1 years old,

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with a mean of 4.3 years old. In Study 1, the demonstrations consisted of both ipsilateral and contralateral gestures, and each gesture was performed either with one hand or with both hands at the same time. Overall, the results showed that there were more contralateral than ipsilateral errors, but the contralateral errors were reduced when children imitated contralateral movements with both hands. Study 2 suggested that the contralateral errors were reduced when the experiment was simplified and the adult only demonstrated unimanual gestures to one side. Finally, Study 3 involved the gesture of touching a table top which either did or did not have two dots on it as targets. Overall, the children made more contralateral than ipsilateral errors, and the errors were significantly reduced if there were no dots on the table to reach for.

Bekkering *et al.* suggested that the children decomposed the perception of the manual gestures into different aspects. These aspects are not represented as physical movements *per se* but rather as semantic entities, goals that are hierarchically organized. The goals of gestures could be an 'object' (e.g. the ear to touch) and 'agent' (e.g. the hand), or a 'movement path'. The reconstruction of the goals into the observed movement is determined by the cognitive resources available to the child for this decomposition–reconstruction process. Some aspects are better preserved (e.g. salient features such as crossed arms) than others (e.g. a single contralateral movement) depending on the position in the hierarchy.

This view is very different from Kephart's idea that there is a rigid neurophysiological limitation that underlies the contralateral error, inasmuch as it implicates cognitive factors and suggests that the contralateral error can be minimized in certain conditions. It also diverges in an interesting way from a view that would reduce imitation to the neurophysiological findings of 'mirror neurons'. Neurophysiological studies have documented the existence of mirror neurons in the premotor cortex of monkeys that are activated during the observation and the execution of the same movement (e.g. Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992). These findings have sometimes been interpreted as providing a basis for the 'direct' translation, almost transparency, between perception and production of human movements. Rizzolatti and colleagues suggest that the mirror neurons relate the understanding of perceived motor events and the initiation of executed motor events. By 'understanding motor events' they mean the individual's capacity to differentiate the observed action from other actions and to use this information in order to act appropriately (Rizzolatti, Fadiga, Gallese & Fogassi, 1996). A related view, although not so much concerned with the recognition of actions, is offered by Jeannerod. Jeannerod (1994) proposes that the neurons responsible for building up a motor image of an act are the same neurons which will later activate during movement planning. Other recent empirical and theoretical work also emphasizes direct perceptual–motor coupling in imitation (Gray, Neisser, Shapiro & Kouns, 1991; Vogt, 1995; Butterworth, 1999).

Direct transduction and mirror neurons may play a role in human imitation, but there is evidence suggesting that this is not the whole story. In addition to the contralateral error noted above (suggesting that there is not always *direct* imitation), there are studies showing that subjects can copy an experimenter's body movements by acting on a mannequin (Goldenberg, 1995; Goldenberg & Hagmann, 1997). Note that in this case the muscle patterns used in producing the movements on a mannequin are quite different from those of the observed gesture (and different from what would be required to reproduce the act with one's own body).

Meltzoff and Moore's (1997) theory articulates a middle ground between the two extremes that imitation is either a direct transduction or necessitates complex semantic analysis. It encompasses both a basic, privileged perceptual–motor linkage and also cognitive analysis that mediates between perception and production of human acts. This theory of imitation emerged from developmental studies, but is applicable to older ages as well. It specifies the metric used to equate perception and production in commensurable terms. According to this theory, perceived acts are coded in terms of 'organ relations', i.e. spatial arrangements between significant body parts, such as hands, head, tongue, lips etc. Organ relations provide a nonverbal coding of human action that is not at the level of motor commands but at the level of the *goal of the act*. This has been used to explain the 'intelligent errors' infants make in trying to re-enact motor behaviors they see (see Meltzoff & Moore, 1995, pp. 52–53; 1997, p. 182).

This goal-directed theory suggests that imitation is founded on a primitive interpretation of what is observed, and is based on a decomposition and analysis of the percept. Thus Meltzoff and Moore have argued that imitation is an active reconstruction of seen gestures. From a developmental perspective, an initial perceptual–cognitive system focusing on organ relations may provide the groundwork for later developments in childhood and adulthood in which inferences about the goals and intentions of human action become ever more complex and hierarchically organized (Meltzoff, 1995; Meltzoff, Gopnik & Repacholi, 1999; Bekkering *et al.*, 2000).

Given this as background we were interested in investigating the types of errors young children make in imitating motor movements, with an eye towards uncovering how young children code human actions. For this purpose we modified Bekkering *et al.*'s study and created 24 gestures by systematically manipulating four factors. The visual monitoring factor had two levels: the adult either moved her hand to a part of the body that the subject could not see on him or herself ('ear') or to her knee, which was visible ('knee'). The spatial endpoint factor had two levels: the adult either touched the specified body part ('on') or simply moved her hand to the space beside it ('near'). The movement path factor had two levels: movements of the hand to the ear or knee either crossed the midline ('contralateral') or not ('ipsilateral'). The number of hands factor had the two levels of either being 'unimanual' or 'bimanual'.

This work extends that done previously because no one has tested hand movements to a visible body part, such as the knee. It is possible that the contralateral error that has previously been reported when moving toward an invisible goal will fall to chance if the movement path is visible to the child. The work also extends previous studies because we manipulated the endpoint of the act as being either on or near the final body part. Bekkering *et al.*'s work with the presence and absence of dots on the table suggests that having a specified endpoint of the act might induce the child to make more errors. If so, then children should make more errors when the adult's act terminates in a clearly defined and specified endpoint on the body (ear or knee). Finally, this study was designed to provide an assessment of imitation in a precisely defined age group. In Bekkering *et al.*'s study the data were means taken from children who had a range of more than 2 years from the youngest to the oldest child. The ages of the children tested here were all within 2 weeks of each other, and as such should provide a firm benchmark for future developmental and neuropsychological studies in normal and atypical populations.

Method

Children

The participants were 32 3-year-old children ($M = 35.95$ months, $SD = 0.19$, range 35.64–36.39 months). The children were recruited by telephone calls from the University of Washington's computerized subject list. Equal numbers of boys and girls participated in the study; 24 children were right-handers, one child was a left-hander, and seven children had not developed a hand preference (see 'Assessment of handedness'). All but one of the children were white. Pre-established criteria for admission into the study were that a child be within ±14 days of his or her 36-month-old birthday, have no known physical, sensory or mental handicap, and feel comfortable with the examiner. Six additional children were eliminated from the study due to procedural errors (two) or because they did not follow instructions or complete the test (four).

Test environment and apparatus

The study was conducted in a room at the university that was unfurnished save for the equipment and furniture needed for the experiment. Two small blankets (51 cm × 81.5 cm) were positioned 25.5 cm away from each other on the floor. The child kneeled on one of them facing the experimenter, who kneeled on the other. The child had his/her back to a one-way mirror of an adjacent room. The parent was seated on a chair in a corner behind and to the right of the child. A video camera behind and to the left of the experimenter recorded the child's whole body. A second camera behind and to the left of the child recorded the experimenter's stimulus presentations. Each camera was fed into a separate video recorder that was housed in the adjacent room.

Test battery: the adult gestures

Each child was shown a test battery consisting of 24 gestures. The list of 24 gestures is shown in Table 1 and a selected eight acts are illustrated in Figure 1. The battery of 24 gestures came from systematically crossing

Table 1 *Twenty-four manual gestures resulting from manipulating four main factors: visual monitoring of body part (ear/knee), spatial endpoint (on/near), movement path (ipsilateral/contralateral), number of hands (unimanual/bimanual)*

	On		Near	
	Ipsilateral	Contralateral	Ipsilateral	Contralateral
Ear	*On-ear (OE)*		*Near-ear (NE)*	
Unimanual				
Right hand	1	2	7	8
Left hand	3	4	9	10
Bimanual	5	6	11	12
Knee	*On-knee(OK)*		*Near-knee (NK)*	
Unimanual				
Right hand	13	14	19	20
Left hand	15	16	21	22
Bimanual	17	18	23	24

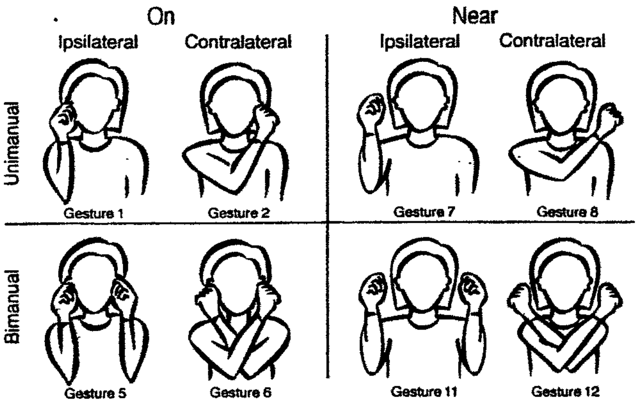

Figure 1 *Examples of gestures demonstrated to the children. Top-left quadrant: ipsilateral and contralateral 'on-ear' demonstrations with the right hand. Top-right quadrant: ipsilateral and contralateral 'near-ear' demonstrations with the right hand. Bottom-left quadrant: ipsilateral and contralateral 'on-ear' demonstrations with both hands. Bottom-right quadrant: ipsilateral and contralateral 'near-ear' demonstrations with both hands. The numbers underneath the pictures refer to the corresponding cells in Table 1.*

four factors. These four factors were: visual monitoring (ear/knee), spatial endpoint (on/near), movement path (ipsilateral/contralateral), number of hands (unimanual/bimanual). The top-left quadrant of Figure 1 depicts unimanual on-ear gestures. One of the gestures is an ipsilateral gesture, and one is a contralateral gesture (corresponding to Table 1, Gestures 1 and 2). The top-right quadrant depicts unimanual near-ear gestures. The bottom row shows the corresponding gestures done bimanually.

The 24 gestures were grouped into four blocks, as shown in Table 1: on-ear (OE), near-ear (NE), on-knee (OK), near-knee (NK). There were six gestures in each of the four blocks. In the OE block, the hand(s) touched the ear lobe(s). In the NE block, the hand(s) were in the air 10 cm beside the ear(s), loosely cupped and the palm of the hand(s) facing the side(s) of the face. In the OK block, the hand(s) touched the knee(s); the palm of the hand(s) was placed on the thigh(s) with the tip of the fingers at the front edge of the knee(s). In the NK block, the hand(s) were put in the air 10 cm above the knee(s); the palm of the hand(s) was facing the knee(s), and the finger tips did not exceed the edge of the knee(s).

All movements directed to the ear(s) were called *ear* demonstrations (OE, NE). All movements directed to the knee(s) were called *knee* demonstrations (OK, NK). The gestures that ended up in contact with a body part were termed *on* demonstrations (OE and OK). The gestures that ended up with the hand in mid-air were termed *near* demonstrations (NE and NK).

Design

The children were randomly assigned to one of four independent groups with eight children per group; thus the stimuli were shown in a counterbalanced order. Group 1 saw the demonstrations in the order OE, NK, NE, OK. Group 2 saw NE, OE, OK, NK. Group 3 saw NK, OK, OE, NE. Group 4 saw OK, NE, NK, OE. Within each block, the six gestures were presented in two sequences. Half the children in each group were male.

Procedure

On arrival at the university, the children and their families were escorted to a play-room where the experimenter interacted with the child. If the child felt comfortable with the experimenter, the parent and child were brought to the test room. The child was told he or she would pretend to travel by boat to Africa and would meet many animals during this trip which wanted to see gestures. The child was asked if he or she was ready to play, and if the child nodded or said 'yes', the experimenter proceeded with a game-like interaction that pilot work revealed appealed to children this age.

First the experimenter began to march around the room and invited the child to follow her. If the child was hesitant to play, the experimenter urged the child to play the marching game while the experimenter and parent smiled and said it would be fun. When the child joined the game, the two of them marched until the experimenter pointed to the blankets where they both could sit. The adult then kneeled down on the blanket and also asked the child to kneel on his/her blanket so they were facing each other. If the child did not kneel, the experimenter asked the child to 'sit like me' or 'kneel down and sit on your feet like this'. The children seemed comfortable in this posture, but in 13% of the trials children chose to sit with their legs out straight in front of them or with their ankles crossed. Such postural variations were allowed so that each child could be maximally comfortable during the test (no differences in responding were observed as a function of the child's posture). To increase the likelihood of keeping the children in a fixed location during the study, the experimenter pretended to row a boat while kneeling on her blanket; she said that a storm would shake the little boats (i.e. the blankets) and so the child should stay firmly in his/her own boat. After the child seemed acclimatized with the room and the adult, usually about 3–5 min, the study began.

The experimenter took out a rubber fish from a box behind her and moved it towards the child. In this game the fish asked the child and adult the following question: 'Can you show me something? Show me something.' (In reality, it was the adult who asked this.) The adult then performed the first gesture, as if in answer to the fish's question, and held the gesture while looking at the child. Each individual gesture was held for approximately 4 s. The presentation of the next gesture occurred when the child completed his/her response or made no more attempts to correct the response. (The first gesture in each block could be repeated twice if the child did not join in the gesturing game right away.) If the child became distracted at any time during the demonstration period, the experimenter would attempt to redirect the child's attention to the task by using phrases such as 'look at me' or 'watch what I am doing'. Regardless of the child's response, the adult said 'very good', or 'yes' in a praising tone of voice before moving onto the next gesture in the battery.

The rubber fish was used to ask the question for the first block, but for the remaining three demonstration blocks the experimenter took other toy animals (a plastic snake, rubber lion, and hand-made monkey puppets) from the box behind her and addressed the child in the same way as before. The children were given two short breaks during the test session to provide a rest and also to maintain the game-like nature of the interaction. The breaks came when the experimenter invited the child to follow her as she marched around the room after the second block of trials and also after the third block of trials. The experimenter did not verbally instruct the child to 'do what I do', 'copy' or 'imitate' during the test. Playing the foregoing games seemed sufficient for eliciting the responses, because when the animal said 'show me something' and the adult performed a gesture, the children wanted to join in too. In this way, the study capitalized on the children's natural tendency to use the adult as a reference for how to act and their desire to partake in imitation games (for further discussions of the social context of imitation games, see Bråten, 1998; Nadel & Butterworth, 1999).

When the test of imitation was over, the experimenter administered a handedness examination. This was a short version of Oldfield's (1971) assessment of handedness. The test consisted of five different activities which the child performed three times each: kicking a ball with the foot, throwing a ball with one hand, knocking on a piece of wood with a plastic hammer, drawing with color pencils on paper, and eating fruit loops out of a bowl. Each test session took a total of approximately 30 min.

Scoring and data reduction

Imitation

There was a total of 32 children. They were scored in a random order by a coder who was kept unaware of the test group of each child. To ensure such 'blind scoring', the videotapes only contained information of the children's imitative responses, and no information about the gesture demonstrated by the adult.

For each trial, the coder recorded ('yes'/'no') whether the child made a specific act of moving his or her hand to the ear or to the knee. The coder also scored whether the movement was a bimanual act or a unimanual one, and if the latter, whether the left or right hand was used. In short, the coder classified each trial as to whether the child's response corresponded to one of the 24 gestures in Table 1 or was a no response (and did so blind to what gesture had been shown to the child).

For the purposes of data reduction, the 25 coding categories were collapsed to determine whether on any particular trial the child was correct or committed an error. An error was tallied if the child did not respond, or if the child reacted to the ear demonstration with a knee response or to the knee demonstration with an ear response. Additionally, an error was tallied if the child responded unimanually to an adult bimanual target or responded bimanually to a unimanual target. Finally, an error was also scored if the child responded ipsilaterally when the adult target was a contralateral demonstration, or conversely contralaterally to an ipsilateral demonstration. The child was not scored as committing an error if he/she used the right hand when the adult used the left or vice versa. (Note that the adult and child were facing each other, so such responses were not clearly 'wrong'. If children move their hand to the same side of space as the adult, this involves the anatomically opposite hand to the adults, because they are facing each other. Previous research has indicated that children younger than about 14 years of age typically respond in this manner (Wapner & Cirillo, 1968).) Moreover, it was not scored as an error if the child did not physically touch the relevant body part (ear or knee) and there was no operational definition about how close to the ear or knee the child's hand needed to be in its final position. This was because our principal questions concerned whether or not children's responses systematically *varied as a function of the adult target demonstration*, and not about fine motor skills on the child's part.[1]

[1] We also scored a subset of the data using stricter criteria, in which the hand had to touch the target body part. The pattern of results does not differ from those reported in the text; in fact, where the data deviate the significant effects reported in the text become stronger. We used the criterion described in the text because it equates the motor skills factor for the 'on' versus 'near' demonstrations. Differences must be due to the efficacy of the stimulus, rather than to difficulty in producing a precisely targeted motor response.

Assessment of handedness

A child was scored as right-handed if he/she performed at least four of the five test activities with the right hand. A child was scored as left-handed if he/she performed four of the five activities with the left hand. If this criterion was not met, the child was scored as having no distinct hand preference.

Results

Each child was presented with 24 gestures, and thus the number of errors could range from 0 to 24 errors. The mean number of errors across the 24 trials was 6.53 (SD = 2.88, median = 7). Preliminary analyses revealed that neither sex of the child nor handedness had a significant influence on the number of errors (respectively, $F(1, 30) = 2.46$, $p > 0.10$; $F(2, 29) < 1$, $p > 0.40$). For all subsequent analyses the proportion of errors made by each child was calculated. The raw number of errors was converted to a proportion because each child was presented 16 unimanual gestures and 8 bimanual ones, and the tests sometimes made comparisons between them. Thus four errors out of 16 trials was tallied as the same proportion as two errors out of eight trials (= 0.25). Also, for all subsequent analyses, nonparametric comparisons are reported because they were deemed more appropriate given the range of scores being analyzed. (For completeness we also analyzed the data parametrically and there was complete agreement between the approaches as to whether or not an effect reached statistical significance.)

Effect of visual monitoring of body part

Half of the gestures shown to the children were ones directed to the ear(s) and half were ones directed to the knee(s). This ear/knee stimulus factor was analyzed to see if it affected performance. The results showed it had no significant effect on the number of errors committed. There was no significant effect as a function of whether or not the target was directed to the ear ($M = 0.28$, SD = 0.12) or the knee ($M = 0.27$, SD = 0.15), $z = 0.32$, $p > 0.70$, suggesting that the ability to visually monitor the response was not a key factor in this study.

Effect of spatial endpoint

Half of the gestures shown to the children were ones that terminated by touching the ear or knee ('on' demonstrations) and half were ones that terminated near the ear or knee ('near' demonstrations). The on/near stimulus factor

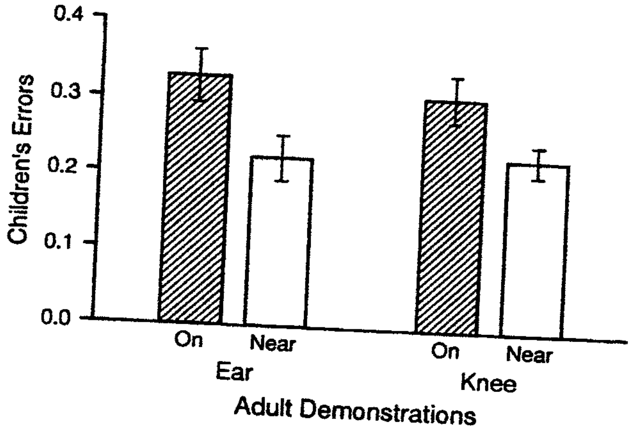

Figure 2 *Means of children's errors (expressed as a proportion of trials administered) in the 'on-ear', 'near-ear', 'on-knee' and 'near-knee' demonstrations (±1 SE).*

had a significant effect. The results showed that significantly more errors occurred in the 'on' demonstrations ($M = 0.32$, SD = 0.15) than in the 'near' demonstrations ($M = 0.23$, SD = 0.12), $z = 3.37$, $p < 0.01$, Wilcoxon matched-pairs signed-ranks test. As shown in Figure 2, these results were equally strong for both the ear and knee gestures. Considering just the ear targets, there were significantly more errors in the 'on' demonstrations ($M = 0.33$, SD = 0.17) than in the 'near' demonstrations ($M = 0.22$, SD = 0.16), $z = 2.32$, $p < 0.03$. Similarly, considering just the knee targets, there were significantly more errors in the 'on' demonstrations ($M = 0.31$, SD = 0.20) than in the 'near' demonstrations ($M = 0.23$, SD = 0.14), $z = 2.37$, $p < 0.02$ (see Figure 2).

Effect of movement path

Half of the gestures shown to the children were ones where the adult's hand was directed to the same side of the body as the hand (ipsilateral demonstrations) and half were directed across midline to the opposite side of the body (contralateral demonstrations). The results showed that significantly more errors occurred in response to the contralateral demonstrations ($M = 0.46$, SD = 0.19) than to the ipsilateral demonstrations ($M = 0.08$, SD = 0.09), $z = 4.86$, $p < 0.0001$, Wilcoxon test (see Figure 3). Thus when the adult showed a contralateral demonstration, whether unimanually or bimanually, the children often made errors. Inspection of these errors revealed that these were virtually all due to children using their ipsilateral hand(s) to make the response. This error is illustrated in Figure 1. When the children saw a unimanual contralateral demonstration, such as gesture 2, they responded with a unimanual ipsilateral gesture, such as gesture 1. Similarly, when

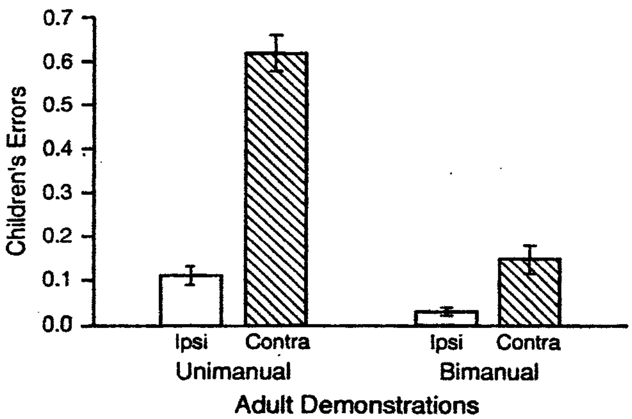

Figure 3 *Means of children's errors (expressed as a proportion of trials administered) in the ipsilateral and contralateral unimanual demonstrations, and in the ipsilateral and contralateral bimanual demonstrations (±1 SE).*

they saw a bimanual contralateral demonstration, such as gesture 6, they tended to respond with a bimanual ipsilateral gesture, such as gesture 5.

Effect of number of hands

The results showed that significantly more errors occurred when the target act was performed with one hand ($M = 0.36$, SD = 0.15) than when performed with both hands ($M = 0.09$, SD = 0.10), $z = 4.86$, $p < 0.0001$, Wilcoxon test, as shown in Figure 3. Considering just the unimanual demonstrations alone, there were significantly more errors in the contralateral demonstrations ($M = 0.62$, SD = 0.24) than in the ipsilateral demonstrations ($M = 0.11$, SD = 0.13), $z = 4.86$, $p < 0.0001$. Similarly, considering just the bimanual demonstrations alone, there were significantly more errors in the contralateral demonstrations ($M = 0.15$, SD = 0.18) than in the ipsilateral demonstrations ($M = 0.03$, SD = 0.08), $z = 2.74$, $p < 0.01$ (see Figure 3).

Mirror responses

When using lateralized gestures, researchers have often explored whether children respond to the same side in space as the adult who is facing them. This is termed a 'mirror response' because the response is to the same spatial direction as the adult, as if looking in a mirror. Bergès and Lézine (1965) tested 3- to 6-year-olds and found that mirror-image responses predominated over non-mirror responses when the child is facing the experimenter, and Wapner and Cirillo (1968) reported that such mirror responses predominated up to abut 10 years old. Because we tested young subjects (3-year-olds) where mirror responses predominate, and because we were interested in questions concerning the number of hands used, whether children crossed midline, and the influence of spatial endpoints, we collapsed mirror and non-mirror responding for the main analyses (see 'Scoring and data reduction'). However, for completeness we also reanalyzed all the 'correct responses' to the unimanual displays, subdividing them to determine whether or not they were mirror responses. As expected from the previous literature, the results showed that children responded with a higher proportion of mirror ($M = 0.88$, SD = 0.12) as opposed to non-mirror ($M = 0.12$, SD = 0.12) responses, $p < 0.001$, Wilcoxon test. Thus, the children were predominantly responding to the same side in space as the adult who faced them.

Discussion

This study investigated errors that 3-year-old children make in imitating human body acts. The study involved showing 24 different acts to each child. The 24 acts were generated by systematically manipulating four factors: visual monitoring of body part (ear/knee), spatial endpoint (on/near), movement path (ipsilateral/contralateral), and number of hands (unimanual/bimanual).

The results showed that visual monitoring had no effect on the error outcome: children made an equal number of errors when imitating gestures to the ears or to the knees.[2] In contrast, the spatial endpoint had a significant effect: children made significantly more errors when a gesture was terminated on a body part than when the same movement terminated near the body part. Similarly, the movement path and number of hands significantly affected errors: the children made more errors after contralateral than after ipsilateral demonstrations, and more errors after unimanual than after bimanual demonstrations.

We interpret the spatial endpoint effect as related to the Bekkering *et al.* (2000) report that children made more imitative errors to gestures involving moving hands to dots on a table than they did to

[2] The children were not always accurate in touching the knee: many touched their thigh or shin instead of the anatomical structure of the knee itself. Future research might use imitation to explore the accuracy and detail of children's body image (Gallagher & Meltzoff, 1996; Gallagher, Butterworth, Lew & Cole, 1998). Our data suggest that knees may not be precisely specified in the 3-year-old's body image, although the knee seems to be coded as being located somewhere in the middle of the leg.

similar gestures without dots. Clearly, the two studies differed substantially in the surface characteristics of the tasks. In the Bekkering *et al.* study, the targets were extrapersonal objects (dots on a table) and the actions were directed outside of body space towards this external object. In our study, the gestures involved intracorporeal relations within the subject's body space. However, despite these surface differences, we think there is a deeper similarity, which explains why a similar pattern of errors was found in both.

Our hypothesis is that when the adult makes a gesture that terminates in touching a specific target ('on' ear/knee or reaching to dots), the child codes that endpoint as the goal of the act. Giving a description of children's mental coding is always tenuous, but we suggest that a central aspect of the child's internal description is something like 'hand to ear/knee/dot' or 'reach to ear/knee/dot'.[3] Importantly, this is not a coding of the act at the level of muscle commands or general movement patterns, but in terms of the outcome or goal of the act. Such coding could lead to errors when the child tried to re-enact the demonstration. The children relying chiefly on this type of goal-directed coding might simply reach to the nearest ear/knee/dot. This would yield an ipsilateral response to an ipsilateral demonstration (correct response) but also to a contralateral one (the principal error obtained). The finding that visual monitoring did not reduce errors also suggests that the motor program is not guided by visual–visual pattern matching between seen movements of self and other. It is consistent with the idea that the selected goal (ear/knee) principally drives the response, activating the motor program that is most strongly connected with achieving that goal (e.g. Prinz, 1990).

The results showed that there were significantly more errors after contralateral demonstrations than after the ipsilateral ones, which replicates previous reports in the literature (Swanson & Benton, 1955; Wapner & Cirillo, 1968; Schofield, 1976; Bekkering *et al.*, 2000). The new information added by this study is that the errors are systematically made by 3-year-olds, an age group that is younger than any tested before, and that the contralateral error was equally strong for the ear and the knee condition, which had not been previously investigated. That children do not accurately imitate the contralateral movement even when they perceive the adult's gesture and their own response within the same perceptual modality shows how pervasive this error is.

When Head first observed the contralateral error in adult patients he thought it was caused by their brain dysfunction. Then, when other researchers found that children showed the same phenomenon, it was described as a primitive reaction tendency to use the hand of the same body side (Quadfasel, 1931) or due to insufficient perceptual–motor experience and neurological immaturity (Kephart, 1971). In line with the interpretation we offered earlier (see also Bekkering *et al.*, 2000), we suggest that the movement path of the hand may be coded at a lower level within a goal hierarchy than the spatial endpoint. Because children cannot easily keep track of multiple goals simultaneously, more dominant ones (e.g. reaching a particular body part that is seen to be touched) may guide the behavior at the expense of less dominant ones (e.g. the precise movement path).

This is merely a hypothesis at this point, but one thing is certain: the data do not support the idea that a fixed neurological constraint prevents contralateral imitation. The relevant data are the drastic reduction in contralateral errors when the adult's demonstration terminates near the ear/knee rather than on it. If there were a fixed constraint causing the contralateral error, a significant reduction in errors would not occur as a function of such a minor change in the stimulus. We believe that the contralateral movement path was more often imitated after 'near' demonstrations because the end position was less defined (it was no longer the clear organ relation of 'hand on ear') and thus was a less dominant goal.

The finding of significantly more errors in response to the unimanual demonstrations than to the bimanual ones replicates Bekkering *et al.* (2000) and can be used to buttress the foregoing interpretation. This underscores that the children's problem in crossing the midline is not solely a problem of motor skills or fixed neurophysiological constraints. Children could readily cross the midline when the model used two hands, but not when she used one. In other words, there was no fixed constraint preventing the contralateral movement. Our hypothesis is that the contralateral movement was neglected when it was demonstrated as a unimanual gesture, because other goals such as reaching to a body part were more dominant. Contralateral movements of both hands led to fewer errors because the crossing of both hands was perceived as a unique feature (crossed arms), which rendered it more dominant. Thus, the goal

[3] Further perceptual details about the act are doubtless preserved, but the goal of the act (expressed as organ relations such as 'hand-on-ear') may still dominate in young children, because organ relations is the original coding used in infancy (Meltzoff & Moore, 1997). Note also that the bimanual contralateral demonstration may be readily imitated because it contains a feature that is easily coded in terms of organ relations ('crossed arms'). Clearly, 3-year-olds are not restricted to organ relation endstates alone; however, coding human acts by endpoints is a developmentally early parsing, which still may exert influence.

of 'cross arms' was reproduced in most cases with few errors (see Figure 3).

Two subsidiary points are also worth making. First, the raw 'familiarity' with a gesture is less important than commonly assumed. Presumably, the adult demonstration of 'crossed arms to ears' used in this study was somewhat novel, or at least not highly practised by children. Yet, they were successful in replicating it. This is compatible with other work suggesting that motor practice with a gesture is not necessary for imitation, inasmuch as infants can imitate completely novel motor acts (Meltzoff, 1988). Second, the issue of handedness is relevant. In this study were 24 right-handers, one left-hander, and seven children who could not be firmly classified. For the unimanual gestures, children of this age tended to use their dominant hand to re-enact the movements, which suggests that selecting the particular hand used by the adult to achieve outcomes is low on the goal hierarchy. Children correctly imitated that the act was unimanual or bimanual but did not seem concerned about the precise hand used.

The results of this study indicate that children are not slavishly mimicking the surface movements that they see. Such findings with 3-year-olds are compatible with Meltzoff and Moore's (1997, 1999) theory that imitation is based on an active mapping, interpretation and recoding of the stimulus – not a reflexive and faithful copy akin to a tape recorder or duplicating machine. If imitation is not automatic, rote or reflexive in its inception in infancy, it is not surprising that it is even less so by 3 years of age. Moreover, the goal-directedness we hypothesize for the 3-year-olds seems a natural developmental outgrowth of the fact that 1.5-year-olds are focused on the goals of an adult's act (Meltzoff, 1995) and that even younger infants code body movements in terms of the endstates of acts and organ relations (Meltzoff & Moore, 1997). Thus the goal-coding that lies at the foundation of imitation originates in infancy, and the goals that are encoded become more complex with age.

On first sight, making errors and failing to faithfully copy exactly what an adult does may seem maladaptive, but it can be interpreted as a strength not a weakness. It is helpful for children to encode human behavior in a way that some aspects are dominant over others instead of all having equal importance. This enables children to focus on the end result and salient or unusual features of a behavior and also facilitates generalizing the information picked up through observation. If children were confined to imitating the literal movements, mimicking at the level of muscle movements instead of goals, they would have difficulties translating the adult's acts into motor plans using their own much smaller bodies, especially when the resting states of the observer and actor do not match. They would also not be able to generalize imitative learning across changes in object characteristics, as for example when the child's and adult's objects were different sizes and therefore required different motor movements to operate. Empirical work shows that young children can generalize imitation across such transformations, including changes in object size (Barnat, Klein & Meltzoff, 1996). Thus, the findings support the idea that human action is categorized by its outcome (Prinz, 1992), goals (Meltzoff & Moore, 1997; Bekkering *et al.*, 2000) and intentions (Meltzoff, 1995) and not at the level of the muscles activated. Simply put: human action is abstractly coded.

In summary, the current empirical findings indicate that 3-year-old children code human behavior and imitate on the basis of goals. The goals are not encoded as equally important but are hierarchically organized. This means that, in some cases, the children create a distorted internal description and will make mistakes. The internal description is distorted because the gesture is decomposed into distinct goals with some getting more emphasis than others. Because young children have difficulties simultaneously integrating multiple goals into one smooth act, they often re-enact those individual goals that are ranked higher. This failure of the children to mimic slavishly is not a disadvantage but gives them the opportunity to focus on relevant and more abstract aspects of the acts they see.

We thus argue that imitation is a creative reconstruction of observed events. This is not only good for the child, but good for the adult scientist. It means that imitation can be used as a window into the child's understanding of human actions. Imitation promises to emerge as a valuable tool for the cognitive scientist and neuroscientist studying action coding.

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